Development of a Robotic Mini-Wrist for Surgical Procedures

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Abstract. *This paper reports the study and development of a milimetric dimension robotics wrist designed to be used in minimally invasive robotic surgery. The conventional surgery in internal structures of human body implies the opening of incisions that allow internal visualization of anatomy, necessary to the execution of specific procedures. With the purpose of increasing the precision of movements and the number of degrees of freedom of the instruments a surgical robot was developed in the Special Robot's Laboratory of PMR-EPUSP. However, the instruments initially tested were adapted from conventional ones what reduced the advantages of the application of robotic techniques. In order to overcome these limitations a robotics wrist was studied and developed, capable to pass through 15mm incisions and accomplish surgical procedures.*

Keywords. *Surgical robot, robot wrist, mechatronics.*

1. Introduction

The motivation of this paper is the increasing applications of robotics in surgery, mainly in the area of minimally invasive surgery.. Robotic applications in surgery began in the 80s, when industrial robots such as the Puma, were adapted for applications in surgical rooms in USA and Japan (Gray&Caldwell, 96). However, safety and performance requirements, nowadays, demand manipulators specifically designed for each surgical field and several classes of manipulators appeared to supply these specific needs.(Vidal et al,2001).

In conventional laparoscopic surgery, doctors use tools with grippers (forceps) that penetrate through canulae of 5 to 10 mm in diameter, while an assistant holds the laparoscopic camera that transmits, to a monitor, images of the internal procedure movements (Fig.1). The great difficulty of using conventional forceps is its limited number of degrees of freedom, the loss of force feedback and the disadvantages of a 2D visualization. Therefore, the robots used in this area offered, initially, an increase in the precision of the tool positioning. However, to improve the surgeon's maneuverability and dexterity it is mandatory to increase the number of degrees of freedom and in some procedures, to provide a tactile return of the force between forceps and human tissues.

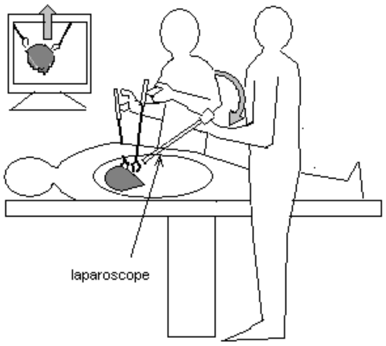

Figure 1: Laparoscopic Surgery

In the field of minimally invasive surgery, in which access to the internal tissues is indirect through video and forceps, a major problem is the small end-effector dimensions needed for the manipulators penetrating through small incisions. In spite of these difficulties, this type of surgery has a great advantage due to low trauma.

The surgical robot prototype, developed at the Special Robots Laboratory of PMR-EPUSP (Department of Mechatronics and Mechanical Systems at Polytechnic School of University of São Paulo), was initially used with conventional forceps (Vidal et al, 2002). The goal was to improve the precision of the surgical procedure and to supply a force feedback. The inherent disadvantages of this adaptation were overcome by the advantage of its use with a wide range of tested tools, allowing the use of this robot in several procedures. This flexibility was possible due to the modular connectors of forceps and robot wrist. The use of several forceps with this robot demanded a simple operation of inserting them in the wrist, as shown in figure 2.

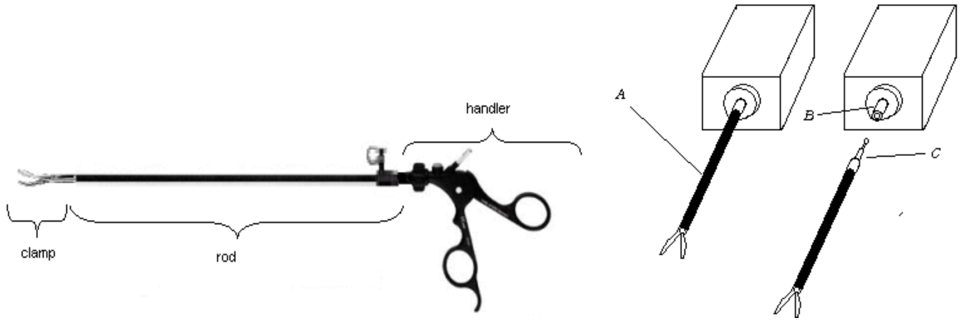

Figure 2- Conventional and adapted forceps

In figure 3, the initial CAD design of the manipulator and the built prototype photo can be seen. In figure 3, are observable the forceps in a vertical guide and the manipulator bar mechanism.

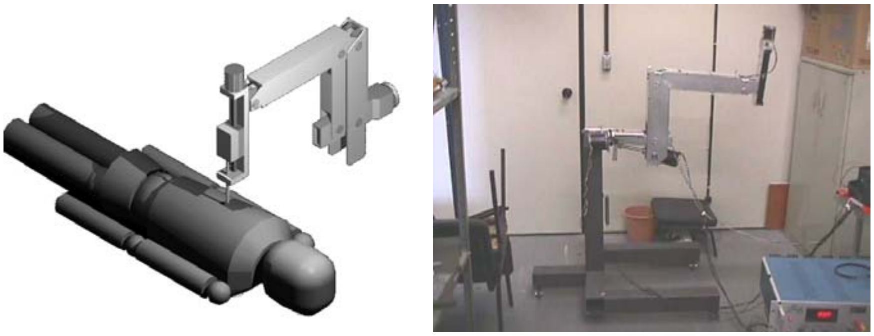

Figure 3. Robot for laparoscopic surgery

In spite of the advantages of using conventional forceps, like the use of devices already accepted, there is a main disadvantage due to the fact that conventional tools reduce the number of degrees of freedom. In conventional open surgery, doctors have three degrees of freedom in his wrist to give the correct orientation to the forceps that is not constrained as in laparoscopic surgery. The same thing happens when a manipulator uses conventional forceps. The solution is to develop wrists that go through small incisions, with the surgeon teleoperating the manipulator, so that his wrist movements are then transferred to the interior of the patient, the trauma to the organism being reduced and dexterity improved.

2 - State of the Art

The instruments used in laparoscopic surgery exhibit 4 degrees of freedom, only one of orientation thus reducing surgeon's maneuverability. In order to overcome this deficiency some researchers have introduced robotic or semi- robotic systems in substitution of the conventional instruments.

The first tentative steps were of altering the conventional instruments in such way as to introduce more wrist degrees of freedom. In 1995, Faraz et al developed a semi-robotic system that consisted of a forceps with an actuated wrist. The doctor's hands, as in the conventional instruments, produced the positioning degrees of freedom while actuators generated the wrist movement.

Figure 4. Forceps with servo controlled wrist (Faraz. 1995)

This idea was not totally implemented due to the difficulty that the surgeon would have to control the robotic wrist with one hand whilst controlling the instrument position and wrist orientation with the same hand. Nakamura et al, 2000, presented a solution. A small lever was placed in the handle of the forceps, providing control of the two wrist degrees of freedom whilst excluding the movement of the gripper (fig.5). However, this command interface was difficult to use and motivated the development of a more ergonomic device (Nakamura et al, 2001). This device used the movement of the index finger to control the wrist.

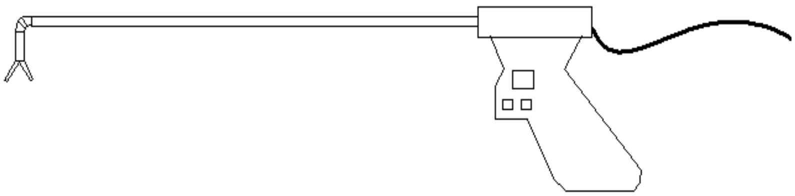

Figure 5. Forceps of Nakamura with two actuated degrees of freedom

This new interface can be seen in figure 6 where the mechanism is controlled by the finger. When the finger executes an upward movement the wrist is moved upwards; the same happens when the finger is bent, and the control system executes a movement of the wrist in the same direction that the finger points.

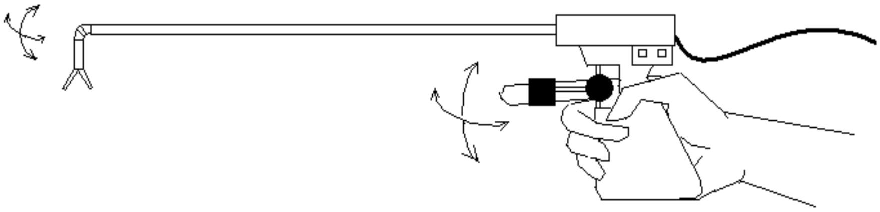

Figure 6. Forceps of Nakamura with finger command interface.

These semi-robotic systems were the first practical solution to improve the difficulties experienced with minimally invasive surgery; however, they presented difficulties with the handle design and they didn't provide any force feedback. An attempt to develop a robotic system that was still tied up to the idea of a semi-active system was accomplished by Bernad et al (Bern 1999). A conventional forceps was used instead of an active wrist and a mechanical support controlled the positioning degrees of freedom. This system could be active or "collaborative", that is to say, some movements are supported by the doctor's hand and others by the atuactors.

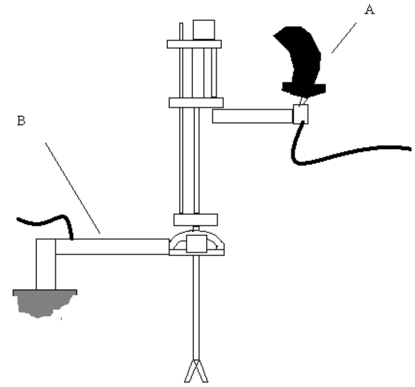

Figure 7 -' Collaborative ' system of Bernad et al (1999)

This system didn't include a robotic wrist that penetrated through small incisions, in spite of being an active system. The two first robotic prototypes, with robotic wrists were developed at Massachusetts Institute of Technology, MIT (Madhani et al, 1998) and at University of California (Murat et al, 1999). The MIT manipulator was based on a 5 bars articulated mechanism, while that of University of California was based on a Stuart platform; both were teleoperated by joysticks with force feedback.

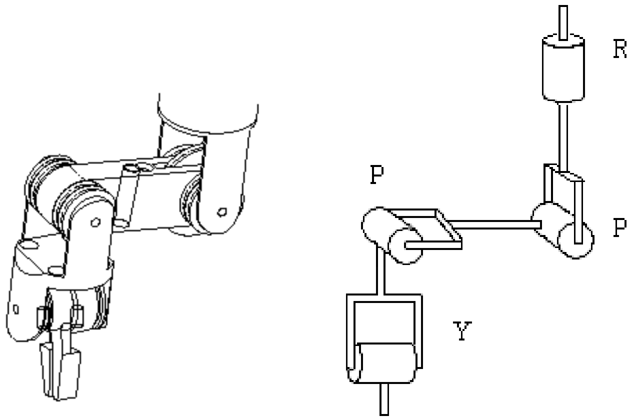

Figure 8. Wrist of 4 degrees of freedom developed by Madhani (in IRON, 98)

The wrist developed at MIT was designed to have at most a 13-mm. diameter and 4 degrees of freedom, excluding the gripper. This wrist had the Roll- Pitch-Yaw (R-P-Y) configuration and the movement transmission of the base servomotors to the wrist was through cables.

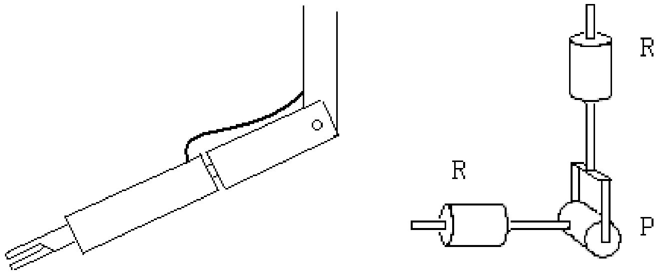

Figure 9. Roll- Pitch- Roll Configuration

The wrist developed in Berkeley (University of California) had a Roll-Pitch-Roll configuration (R-P-R) and was designed not to exceed 15mm of diameter; the final prototype had 10 mm (Murat et al, 1999). The great difficulty of this wrist configuration was to produce a Roll after a Pitch; however, this configuration shows advantages in suturing because a turn around the suture axis (fig 10) is the movement involved. Placing a hydraulic actuator in the wrist solved the difficulty of the roll movement, because electric actuators with this dimension would not reach the required torque.

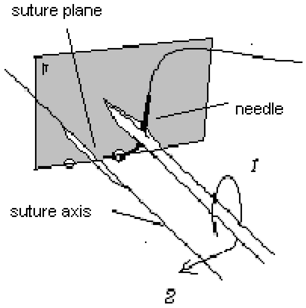

Figure 10. Suture movement

3 - Project of the wrist mechanism

With the purpose of replacing conventional forceps, a wrist capable of going through small incisions was designed and developed. The wrist‘s project began with the specification of the system needs and conversion into project requirements.

3.1 - Specifications

The main needs to be supplied by any designed wrist are:

- Increase the surgeon’s maneuverability, by increasing the number of degrees of freedom;
- Allow a compatible range of movements with the movements of the surgeon’s hand;
- Be modular, that it’s to say, to allow ease change of tools;
- Be sterilizeable;
- Possess a gripper that easily holds a surgical needle;
- Show small dimensions that allow going through small incisions.

Analyzing these needs and looking at the existing bibliography, the numerical requirements can be reached. Three degrees of freedom (Roll, Pitch, Yaw) are needed to increase the surgeon's maneuverability, so that he achieves any orientation of the gripper in the workspace. The range of these degrees of freedom should be compatible with the range of degrees of freedom of the surgeon’s hand. Analyzing the written material on the subject and making measurements, the mean value of the human wrist movement is obtained. According to Rosheim(1989), the mean lateral deviation of the human wrist is 15° outside and 40-45° inside, and tends to reach extension and flexion of approximately 85°. The pulse mean torsion is 170° (Fig.8). If the manipulator wrist is not compatible to these data the surgeon cannot teleoperate the robot in an ergonomic way, as if he is accomplishing a procedure with his own hands.

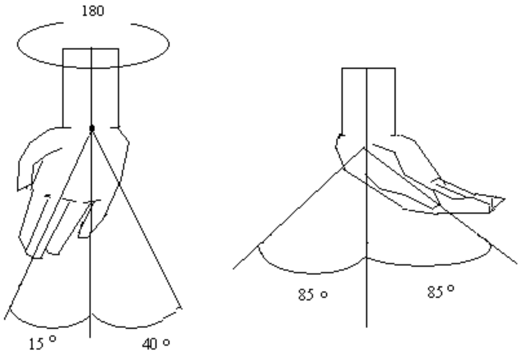

Figure11. Torsion, lateral deviation and pulse flexion.

` Analyzing the literature it’s observable that the values of displacement of the mechanical wrists are generally the same or superior, allowing a movement range better than that of a human hand. The wrist developed by Madhani et al (1998) was designed to possess displacements in Pitch and Yaw of + / - 90°, while the wrist developed by Murat et al (1999) possessed a range of 360°, 90° and-90°(Roll-Pitch-Roll), respectively.

3.2 - Study of the gripper

A great number of tool types exists for laparoscopic surgery that indicates the need of specific tools for specific procedures. A claw configuration was chosen because not only can it grip tissue, but it can also hold a surgical needle.

Figure 12. a) Needle tongs b) Scissors c) Tongs to seize d) Tongs to seize

In figure 12 can be observed some types of surgical tongs that were considered. Those shown in figure 12a are used to hold needles, while those in figure 12b are used as scissors, in figure 12c are of general nature and in figure 12d are designed to hold and move tissue.

3.3 - Mechanism of the Wrist

The wrist was designed to have servomotors as actuators and the movement transmission for the pitch axis was accomplished through cables and to roll axis through reducers directly connected at the axis.

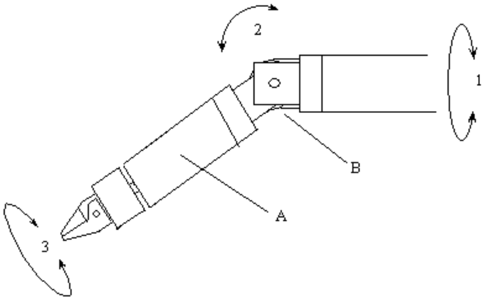

Figure13. The wrist with R-P-R movement.

In figure 13, the design of the wrist is seen, with three degrees of freedom: the rotations for axis 1 and 2 are produced by external servomotors and the rotation for axis 3 by a mini servomotor placed in position A . Due to the need of reducing the diameter and the length of the wrist, another wrist was designed with the movement transmitted to axis 3 by an universal joint (fig 14).

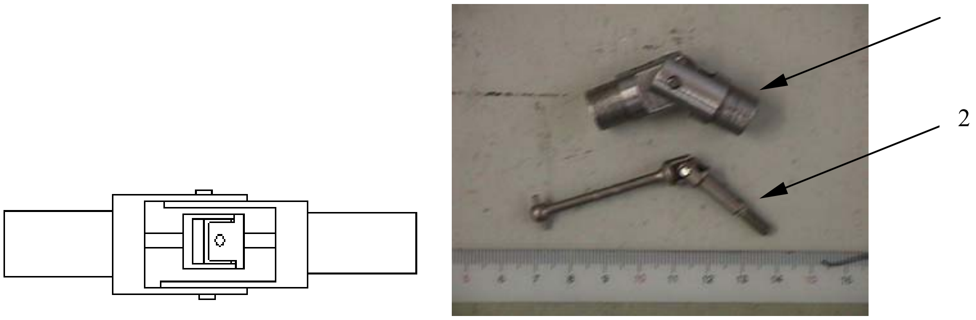

Figure14. Drawing of the wrist with universal joint and photo of the components.

The main advantage of this wrist is that the mini servomotor was used to reduce the length of the wrist and to facilitate sterilization. It is observable at the photo the wrist articulation (1) and the universal joint. The main disadvantage of using universal joint is the range of angular displacement of the joint, approximately +/- 55 °.

4. Conclusions

This paper verified the limitations of the modular wrist developed at PMR-EPUSP, which used adapted conventional forceps. A solution for these limitations was presented using a mini-wrist that penetrates in the body. A review of the literature supplied the guidelines to transform the needs into project requirements. The development of a wrist with R-P-R configuration, using two types of movement transmission for the second axis in Roll, was accomplished.

Acknowledgement

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